Title
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DELIGHT2 DAYLIGHTING ANALYSIS IN ENERGY PLUS: INTEGRATION AND PRELIMINARY USER RESULTS

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ABSTRACT

DElight is a simulation engine for daylight and electric lighting system analysis in buildings. DElight calculates interior illuminance levels from daylight, and the subsequent contribution required from electric lighting to meet a desired interior illuminance. DElight has been specifically designed to integrate with building thermal simulation tools. This paper updates the DElight capability set, the status of integration into the simulation tool EnergyPlus, and describes a sample analysis of a simple model from the user perspective.

INTRODUCTION

In a previous paper (Hitchcock, et al., 2003) we described the then current and planned capabilities and analysis methods for DElight2, a simulation engine for daylight and electric lighting system analysis in buildings. Major DElight2 enhancements included full radiosity interreflection calculations and analysis of complex fenestration systems (CFSs). DElight was specifically designed to integrate with whole-building thermal simulation tools on a time-step basis.

Since then, DElight2 implementation and full integration with the energy analysis tool EnergyPlus v1.2.1 (Crawley, et al., 2001) have been completed and the combined tool is undergoing validation and preliminary use. This paper presents:

(1) A brief update on DElight capabilities.

(2) A discussion on the use of Bidirectional Transmission Distribution Functions (BTDFs), both internally generated and from external sources ([e.g., IEA-SHC Task 21, 2000), as Complex Fenestration Systems (CFS) characterizations in DElight analyses. BTDFs are now becoming more widely available from measurement and simulation activities (IEA-SHC Task 31). This is an important new analysis capability in DElight2. Validation results for DElight analysis of CFS systems based on BTDFs will also be presented and discussed.

(3) A discussion of results for a simple test case that highlights the DElight-EnergyPlus integration features. This example has two aperture variations, a simple window and the same aperture with a light redirecting CFS type. These variations show quantitatively the impact of the daylighting system, including interior illuminance, and the hourly effect on lighting electricity use for a lighting system model.

DELIGHT2 CURRENT CAPABILITIES

DElight2 capabilities added since our previous paper include:

- Building Geometry Library extensions, including (1) arbitrary polygon surfaces, subsurfaces, gridding, and coplanarity testing for 3D polygon vertex data sets, and (2) partial surface-to-surface visibility testing (a full implementation will be completed soon).
- External data file inputs and pre-processing for use in DElight analyses include IESNA (IESNA, 1987) and RAD (Larson, 1998) file formats for lighting fixture data, and sky data. Although DElight does not currently use this data format for analyzing lighting fixtures, this could be implemented in the future. This data format was used as part of the validation study described below for importing sky luminance data.
- Full implementation of BTDF-based CFS analysis, discussed in detail below.
- Full integration with EnergyPlus, discussed in detail and including an example below.

COMPLEX FENESTRATION SYSTEMS

The ability to analyze CFSs characterized by BTDF datasets both internally generated and input from external data files in IEA Task 21 format has been fully implemented.

In addition to analyzing simple fenestration systems, DElight includes the capability of analyzing complex fenestration systems such as geometrically complicated static shading systems (e.g., roof monitors) and/or optically complicated glazings (e.g., prismatic or holographic glass). This capability is based on characterizing these CFSs using bi-directional transmittance distribution functions (BTDF). In general, BTDF data for a specific CFS must be either measured or simulated (e.g., using ray-tracing techniques) prior to employing DElight to analyze it within EnergyPlus.

The current implementation of DElight CFS calculations within EnergyPlus supports two approaches to the input of BTDF, an analytical approach and a file-based approach. Two analytical CFS BTDF types are currently supported, WINDOW and LIGHTSHELF (the actual analytical implementation in DElight2 for the latter should perhaps more correctly be called a light REDIRECTING system). The file input capability allows access to BTDF libraries being developed by others. The file-based approach requires that a user have access to a data file containing raw BTDF data that DElight reads as additional input during its analysis calculations. BTDF data files are described separately since it is anticipated that individual EnergyPlus users will not create these data files themselves.

DELIGHT – ENERGYPLUS INTEGRATION

The DElight – EnergyPlus integration effort has now been completely implemented. This allows DElight daylighting analyses to be used to support the analysis of impacts of daylighting and lighting control algorithms in EnergyPlus thermal and energy use simulations. The integration at the interface level allows DElight input to be completely specified in EnergyPlus input language, and also provides analysis output reporting, and runtime error handling through EnergyPlus facilities.

We will illustrate the details of how an integrated DElight2-EnergyPlus analysis is specified and how the results are reported for a simple example.

Example Analysis

The example is a simple model with two 4.5m square, 2.5m high, side-by-side zones with identically placed window apertures in the center of their south walls. Each zone has an electric lighting system whose maximum power is reduced by the daylighting incident on illuminance sensors at a 0.9m workplane height located on a centerline perpendicular to the window aperture. In Zone 1, the aperture is a simple double-glazed window; in Zone 2 the aperture is an analytical CFS that acts like an upward-redirecting light system – all downward directed light from the sky incident on this CFS is redirected upward at the same angle from the horizontal into the space. This upward-redirected light tends to illuminate the ceiling and diffusely reflect light deeper into Zone 2 than the window does in Zone 1.

Example Inputs

Figure 3 at the end of the paper shows the relevant parts of the thermal and DElight-related inputs for Zone 2 of this example. The `ZONE, LIGHTS, SURFACE: HeatTransfer,` and `SURFACE: HeatTransfer:Sub` objects are standard building components for thermal analysis. The remaining three objects (indicated in bold font) specify the details of the DElight2 analysis. Comments embedded in the input syntax with a "!" character explain the various parameters in more detail.

- `DAYLIGHTING:DELIGHT`

The first input object required for invoking the DElight method is the Daylighting:DElight object, which defines the parameters of each daylighting zone within a building. This object must be associated with a specific thermal zone within the building for which the reduction in electric lighting due to daylight illuminance will be accounted.

- `DAYLIGHTING:DELIGHT:Reference Point`

The second input object required for invoking the DElight method is the Daylighting: DElight: Reference Point object, which defines the parameters of each Reference Point within the associated DElight daylighting zone. This object must be associated with a specific Daylighting: DElight object instance. There may be up to a maximum of 100 Reference Points for each DElight daylighting zone. Each Reference Point that is input does NOT need to be included in the control of the electric lighting system within the zone. This is determined by the fraction of the zone controlled by each Reference Point (which can be input as 0).

- `DAYLIGHTING:DELIGHT:Complex Fenestration`

The third input object related to the DElight method is the Daylighting:DElight: Complex Fenestration object. The DElight daylighting analysis method can be applied to daylighting zones that contain only simple fenestration systems such as windows and skylights that are standard EnergyPlus sub-surfaces. In this situation, no Daylighting: DElight: Complex Fenestration object would be input. The example Zone 2 analytical CFS BTDF type is the LIGHTSHELF (more correctly, a light REDIRECTING system).

DElight only deals with the visible spectrum of light transmitted through a Complex Fenestration. To account for the solar/thermal influences of a Complex Fenestration, a geometrically coincident subsurface that will be accounted for by methods already within EnergyPlus must be defined in the input data file and referenced here. This must be a valid name that has been associated with a Surface:HeatTransfer:Sub WINDOW contained in the same EnergyPlus input data file, as shown earlier in the example input. The geometry for the Complex Fenestration is taken from the geometry input for this standard EnergyPlus subsurface, hence the term "Doppelganger." This is an interim solution to the issue of accounting for solar/thermal influences that will likely change as techniques analogous to the daylighting analysis of BTDF are developed.

Example Outputs

The `Report Variable` specification shown in Fig. 3 produces a standard EnergyPlus report, *Ltg Power Multiplier from Daylighting*. This is the amount by which the overhead electric lighting power in a zone is multiplied due to usage of DElight calculated daylighting to dim or switch electric lights. For example, if the multiplier is M and the electric power without dimming is P, then the electric power with dimming is M*P. The multiplier varies from 0.0, which corresponds to maximum dimming (zero electric lighting), to 1.0, which corresponds to no dimming. This output report is produced in a comma-separated-value format that can be directly imported into a spreadsheet and plotted. Figure 1 below shows the plotted lighting power multipliers for one week in January for the example.

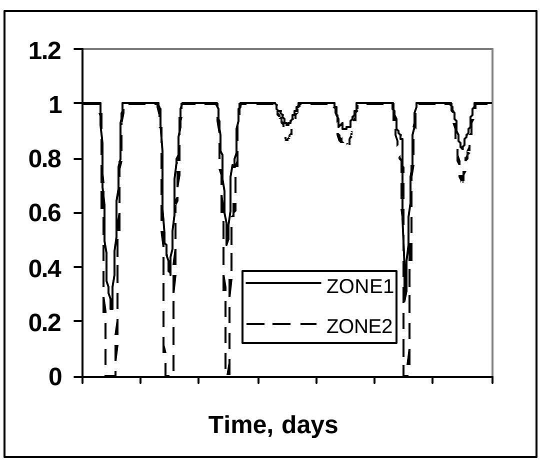

Figure 1. Lighting power multipliers forZONE1 with window and ZONE2 with upward-redirecting CFS.

For the seven-day simulation period shown, three of the days were cloudy and four were sunny. On cloudy days, the lighting power reductions were no more than about 10% for the window and 20% for the CFS. On sunny days, the reductions were 50% to 70% for the window and fully 100% for the CFS. These results clearly show the ability of the CFS to redirect light much farther into the space from the aperture, an expected result. An annual analysis could directly compare the difference in lighting electricity consumption and peak demand for a real climate, and the subsequent impact on thermal loads within the zone from this electric lighting.

This example shows quantitatively the impact of daylighting systems through the hourly effect on lighting electricity use when sensors that detect the amount of natural light and controls that correspondingly modulate lighting electricity are simulated.

VALIDATION

DElight2 recently participated in an IEA Solar Heating and Cooling Annex Task 31 Daylighting validation exercise specifically focused on the ability to simulate CFS performance, as characterized by measured BTDFs (Maamari, et al., 2005). The comparisons were based on measurements and corresponding simulations in a simple-geometry test box for combinatons of CFS BTDFs and measured skies.

The DElight2 results for a particular combination of a CIE overcast sky and a measured BTDF representing Serraglaze (a light-redirecting glazing) are shown in Figure 2 below. The data values represent illuminances at defined sensor positions, spaced equidistantly along a floor-level symmetrical center line, from light incident through an aperture centered in the top of the square test box. The lines represent the simulation results; the data points with 10% error bars represent the measurements. The upper dataset represents an empty aperture; the lower dataset a CFS in the aperture. In this case, the RMS difference was on the order of a few percent. For all combinations of comparisons performed, the aggregate RMS differences were on the order of 10%. These early results are promising, and indicate that the simulated accuracies are good enough that DElight is suitable for doing quantitative estimates of performance of these systems for building design purposes.

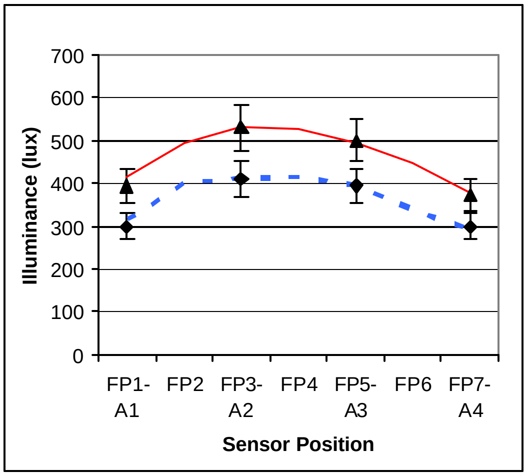

Figure 2. Comparison of measured and simulated illuminances {lux} at selected sensor positions located equidistantly along a floor-level symmetrically centered line in a simple-geometry box validation test case. (The sensor position labels have no particular meaning.)

CONCLUSIONS

This material shows that the integrated EnergyPlus-DElight tool is robust, usable, and capable of providing sufficiently accurate quantitative information about the performance of daylighting and lighting control systems in actual buildings, suitable for aperture selection and system design.

The methods related to characterizing and analyzing CFS using BTDF are still evolving. DElight is an early implementation of CFS analysis methods. These methods, and the input associated with them here, will likely change in the future.

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```
ZONE,
  Zone2,            !- Zone Name
  ...;

LIGHTS,
  Zone2,            !- Zone Name
  BLDG Sch   3,     !- SCHEDULE Name
  1464.375,         !- Design Level {W}
  ...;

SURFACE:HeatTransfer,
  Zone2-WallExt-South,     !- User Supplied Surface Name
  WALL,             !- Surface Type
  Vabs0.50,         !- Construction Name of the Surface
  Zone2,            !- InsideFaceEnvironment
  ...;

SURFACE:HeatTransfer:Sub,
  Zone2-WallExt-South-Wndo0,  !- User Supplied Surface Name
  WINDOW,             !- Surface Type
  DOUBLE PANE WINDOW, !- Construction Name of the Surface
  Zone2-WallExt-South,!- Base Surface Name
  ...;

DAYLIGHTING:DELIGHT,
  DElight Zone2,    !- User Supplied DElight Zone Name
  Zone2,            !- Host Zone Name
  1,                !- Lighting control type
  0.0,              !- Min input power fraction for continuous dimming
  0.0,              !- Min light output fraction for continuous dimming
  0,                !- Number of steps for stepped control
  1.0,              !- Probability lighting will be reset when needed
  0.5;              !- Gridding Resolution {m2}

DAYLIGHTING:DELIGHT:Reference Point,
  RefPt 4,          !- User Supplied Reference Point Name
  DElight Zone2,    !- DElight Zone Name
  2.25,             !- X-coordinate of reference point {m}
  4.0,              !- Y-coordinate of reference point {m}
  0.9,              !- Z-coordinate of reference point {m}
  1.0,              !- Fraction of zone controlled by reference point
  1000.;            !- Illuminance setpoint at reference point {lux}

DAYLIGHTING:DELIGHT:Complex Fenestration,
  CFS-REDIRECT,     !- User Supplied Complex Fenestration Name
  BTDF^GEN^LIGHTSHELF^0.25^20.0^1.00^0.5, !- Complex Fenestration Type
  Zone2-WallExt-South,                    !- Base Surface Name
  Zone2-WallExt-South-Wndo0,              !- Doppelganger Surface Name
  0.0;              !- Fenestration Rotation {deg}
```

Figure 3. EnergyPlus zone, lighting, surface, window, reporting, and daylighting objects for the example test case discussed in the text.